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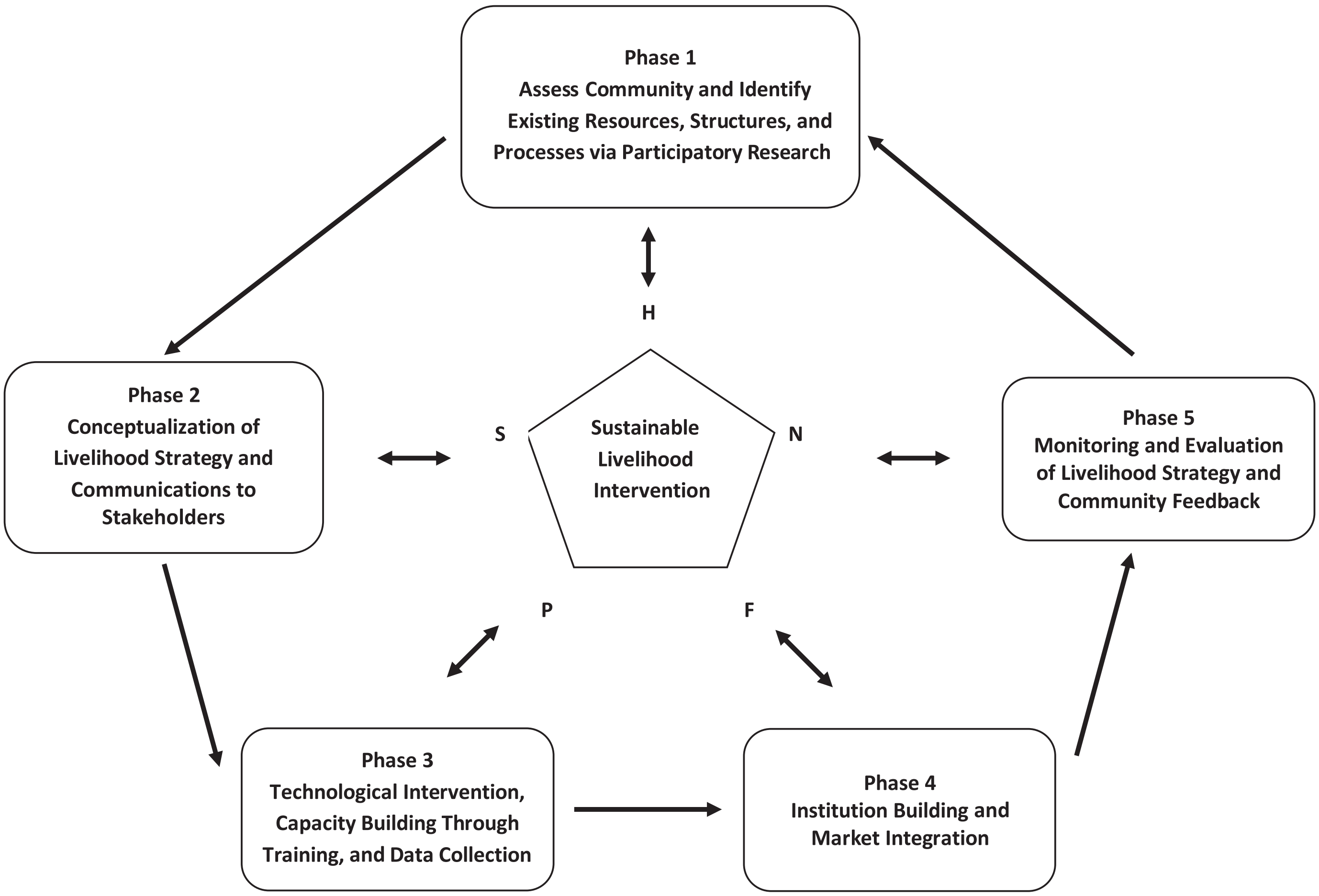

FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

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Resource integration in smallholder farms for sustainable livelihoods in developing countries

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Abstract: The need for sustainable agricultural advancements remain at the forefront of global development practices, with smallholder farms emerging as an essential factor in creating long-lasting improvements in food security, enhanced nutrition, and economic development. Sustainable intensification and diversification in small farms can achieve these outcomes and often take the form of integration among farm resources to achieve sustainable livelihood. However, such integration is promoted in the form of integrated farming system (IFS) models as a single farm innovation for the smallholder systems of developing countries without considering the heterogeneity and priorities of farm families. Using the sustainable livelihoods (SL) framework, we propose a modified model for IFS promotion, particularly applicable for developing nations. The model modifies the standard SL model and illustrates how, based on the resources and vulnerabilities of small farms, IFS needs to be customised to achieve multifunctional benefits for smallholder farmers depending on the locations. It should first integrate the available assets of a farm, and then consider the micro-intervention that are strategically designed in a conscious livelihood based on their socioeconomic, bio-physical, political, and cultural situations. The goal of this article is to achieve multiple desirable livelihood outcomes at farm and community levels. This conceptualisation should help to develop IFS

ABOUT THE AUTHORS

Our diverse and international team of authors from three different Universities enjoy sharing their understanding and knowledge for strategic sustainable development. This unique group of researchers appreciate working on multidisciplinary and collaborative projects that enable them and others to advance the knowledge and importance of multifaceted programs in various resource-limited settings. Goswami, Saha, and Nandi along with their students and collaborators have implemented projects on integrated rural development in various parts of the world. We all share a common platform of Global HealthShare® Initiative (http://ghs.ucdavis.edu) which is a project-based program designed to discover, develop, and deliver products, services, and provide training to address some of the world's most challenging global health problems to create healthy communities and healthy economies.

PUBLIC INTEREST STATEMENT

During past years, individually or collectively, our team made substantial research effort to understand how resource integration should play a key role, particularly in developing a sustainable livelihood in resource-limited regions. In this article, we attempted to capture our cumulative ideas, outlined a modified model and proposed a process of integration by having feedback from the stakeholders across different regions. We believe that attentive theoretical assessment is critical to understand which is not sustainable about current or past agricultural and food systems. Also, for successful transitions towards smallholder agricultural and rural sustainability at farm, community, regional, national, and international levels—our proposed process can be implemented phase-wise for measurable, adjustable, and sustainable community-level integrated farming system intervention in a "cyclic-adaptation" manner.

models based on local resources and farmers' priorities that become more flexible than rigid.

Subjects: Environment & Agriculture; Food Science & Technology; Social Sciences

Keywords: sustainable livelihoods; resource integration; integrated farming; sustainable agriculture

1. Introduction

It is estimated that the human population will surpass 9 billion by the year 2050 (United Nations, 2013). To meet the changing and diverse dietary needs of a growing world population, food production will have to be more than doubled globally and tripled in developing countries (Mazoyer & Roudart, 2006). As a result, agricultural investments need to be intensified on a broader basis across the globe (Conway & Barbier, 2013). Many studies on agricultural systems suggest that an increase in food production could potentially increase environmental poverty (Hazell & Wood, 2008; West et al., 2014). Therefore, it is crucial to meet this growing demand for food without negatively affecting ecological sustainability and social equitability, particularly in developing regions. Nearly 1.5 billion people live in smallholder households of developing nations (Davis et al., 2010), and subsistence farming has significant implications for these smallholder farms (SHF), for which both sustainable intensification and diversification in farming systems are necessary for sustaining livelihoods (Garnett et al., 2013; Tipraqsa, Craswell, Noble, & Schmidt-Vogt, 2007). This is due to the fact that smallholders across the globe have limited access to resources and are at risk of climatic variations (Morton, 2007).

SHFs have emerged as an essential factor in international development discourse because of their abundance and potential for addressing malnutrition (Food & Agriculture Organisation [FAO], 2012). Furthermore, sustainable intensification of these small farms can address the critical need for "feeding the future" generations (Godfray et al., 2010). A large study examining smallholder agriculture covering 286 projects, over 37 million hectares in 57 developing countries, found that when sustainable agriculture was adopted, average crop yield increased by 79% (FAO, 2012). Higher yield also means increased household food security and higher household income, especially when money was saved through reduced fertilizer and pesticide use (Pretty, 2008).

One of the most common ways to encourage sustainable management of resources in small farms is through the practice of integrated farming where species diversification and resource integration contribute to regaining productivity (Prein, 2002; Tipraqsa et al., 2007). There has been increased interest in such bio-diverse and ecological integrated farming systems (IFS) that maintain harmony with natural ecological systems, developed by small family farms in different parts of the globe (Altieri, 1995; Altieri & Koohafkan, 2008; Gliessman, 2015). Intensification and diversification in such systems ensure that agriculture-driven growth is inclusive, pro-poor, and environmentally sustainable (Altieri, Funes-Monzote, & Petersen, 2012). Although not all IFS employed by SHF are ecologically sound, they possess an inherent capacity to integrate farm components and diversify resource use, leading to increased sustainability of farming systems (Altieri & Koohafkan, 2008). The large number of small farms involved in global agricultural development, and their inherent capacity to enhance farm-level sustainability, provides a pragmatic foundation for studying IFS in developing nations.

Functional models of existing agricultural extension in developing nations are linear, top-down, and prescriptive in nature, and are prepared to deliver technology-transfer functions (Sulaiman & Hall, 2002). These models fail to address the complex, diverse, and risk-prone smallholder systems in developing nations, where IFS can be an important option for intensification and diversification (Warner, 2008). IFS is a combination of technology/practices that might be affected by farm resources, goals of the farm families, and external factors such as market and climate. Conventional technology-transfer model is insufficient to promote IFS due to lack of its capacity to develop location-specific solutions for diverse smallholder systems. An alternative conceptualisation and model for IFS is required to promote IFS in smallholder systems considering the farm resources and a farm's meso and macro environments. Moreover, the model should be grounded on the priorities of the farm family and their participation in IFS planning.

The objectives of this study are to establish and propose a sustainable model for promoting IFS within a theoretical framework and propose a process so that these systems can be taken up as a model of agricultural development for small farms in developing nations. Most studies in the area of IFS have either been studied from a socioeconomic or an ecological perspective. This creates a serious gap in the literature involving smallholder integrated farms as socio-ecological units (Amekawa, 2011). The sustainable livelihood (SL) framework (Scoones, 1998) provides scope for integrating both socioeconomic and ecological perspectives in the context of IFS, and identifies resource integration as a livelihood strategy undertaken by small farmers. We have organised our study in the context of IFS in developing nations and have proposed IFS as an embodiment of agro-ecological principles and socio-ecological process. This is followed by the illustration of a theoretical framework that captures the ecological and socioeconomic aspects of IFS within the SL framework, for both farm and community level. The factors of integration in IFS are considered and described as a part of the model. Our overarching goal is to investigate the implications of such conceptualisation for smallholder systems in developing nations with special reference to agricultural research and extension.

2. Integrated farming system models: perspectives, limitations, and recommendations

2.1. IFS models in developing nations: Agricultural research, Affordability, and Implementation

For decades, global agriculture has been characterised by production surpluses in industrialised countries and stagnated growth in non-industrialised countries (Zhen et al., 2005). Global economic growth has transformed agriculture into a more market-driven sector, providing investment opportunities even in less-industrialised countries (Vincke, 1988). Conversely, in most developing countries, average rates of land ownership have declined. In India, for example, 80 million out of 105 million operational holdings are smaller than one hectare (Sharma, 2011), and Food and Agricultural Organisation (FAO) reports an estimated 85% of the farming population in India as marginal family farms (Food and Agriculture Organization [FAO STAT], 2013). Because of the increasing population and declining availability of land, there is barely any opportunity for horizontal expansion of food production (Anderson & Genicot, 2015), in spite of increased opportunities of market integration. Integrating appropriate components in farming systems, that ensures higher productivity while using less space and time, is the only logical course of action for long-term sustainability in small farms. In brief, ideal sustainable farming systems must meet farmers' needs without jeopardising the natural resources.

Industrial, technology-driven models for integrated farming are often found to be unproductive in the developing world (Edwards, 1997) due to resource limitations, affordability, and implementation challenges. The models also encourage decrease in crop diversity and the systematic neglect of traditional cropping systems (Johns, Powell, Maundu, & Eyzaguirre, 2013). Consequently, decreased investments and surges in food prices contributed to food insecurity and threatened the progress of the millennium development goals (Cordell, Drangert, & White, 2009). Although current models of agricultural research are able to create significant increases in food production, they have been unsuccessful in addressing the needs of a large percentage of small farms in risk-prone areas (Chambers, Pacey, & Thrup, 1989). Sustainable food production systems at grassroots and their integration with larger markets could have avoided this problem by collaborating with local, community-based operations and external investments. By creating hybrid value chains that provide profitable results for both investors and the citizen sector, agricultural markets could see an increase in crop yield, product value, and more-efficient farming methods (Drayton & Budinich, 2010).

In many developing nations, the model of agricultural extension is linear and top-down in orientation, and is predisposed with technology-transfer functions. Although human resource development and advisory work are integral to many extension services, the problem-solving approach of extension has remained far from reality in numerous agricultural research and extension systems (Rivera, 2000). This model fits well in resource-rich and homogeneous farming systems, where extension system is predominantly trained in technology-transfer functions, but the model fails to address the complex, diverse, and risk-prone smallholder systems in developing nations (Anandajayasekeram, Puskur, Workneh, & Hoekstra, 2008). Smallholder system is characterised by huge diversity and resource constraints, and the linear model of technology transfer is likely to fail or achieve limited success. This is true for IFS, which is not a single piece of innovation, but a combination of technical solutions in agriculture to address local problems and quickly re-prioritise them. These combinations are again guided by farm heterogeneity and the goal of farm families. Hence, a farmer-centric research and extension system must be in place to develop appropriate IFS models followed by its farm-specific refinement.

Agricultural research in developing countries has not been typically done based on farmers' participation in technology development and their farm-level assessment and refinement (Hoffmann, Probst, & Christinck, 2007) with a few exceptions (e.g. Farm Science Centre in India). Research stations develop IFS models assessed in terms of productivity and profitability parameters only for a broad agro-climatic zone covering a large number of smallholders. Unfortunately, public extension, in most instances, tries to offer these "standardised" IFS models with limited success because: (a) agricultural research does not consider the factors that influence spontaneous integration in SHF; (b) conditions in research stations are controlled and, thus, different from those of farmers' situations; and (c) neither research nor extension draw on the desirable livelihood outcome of SHF, which is diverse and dynamic in nature (Roling & Wagemakers, 2000).

There are two separate contexts of integrated farming in the developing world—first, the practice of integrated farming has evolved and thrived in risk-prone ecosystems, and second, the system has evolved as an alternative/modified way of farming due to changing socioeconomic, political, and climatic circumstances. This adaptation, allowed for the efficient use of resources, is essential in order to secure the livelihoods of farmers, establish farming systems, and sustain ecosystems. Sustainable integrated farms began to evolve as an alternative way of farming in many parts of the developing world as a method of crop cultivation because of its multi-functionality such as complementary weed and pest control, reduced application of agrochemicals, minimised environmental degradation, enhanced dietary standards, generation of gainful employment for family members, and improved resilience against climatic variations (Kathiresan, 2007). Many of these farms operate in challenged ecosystems in the developing world, where prescriptive green revolution technologies barely intervened. In the context of structural adjustment programs, farmers of many developing nations did not have access to extension services. Some nations (e.g. Thailand, Mexico, Cuba, etc.) resorted to sustainable agriculture as an alternative to conventional external-input agriculture. Although public sector investment in agriculture has increased in some instances, and program on food security was undertaken (e.g. National Food Security Mission in India), essential change in the agricultural production or farming systems has not been mainstreamed. Many of these initiatives were either created by the farmers themselves or were promoted by organisations involved with sustainable agricultural interventions (Das, 2013). The main objective of these efforts was to lower the dependency on external inputs, and to strengthen self-sufficient dynamics within the communities. Depending on the agro-ecological circumstances, different types of integration have been practiced since ancient times, and indigenous knowledge of the best practices for the farmers was instantly incorporated in respective farm systems (Food & Agriculture Organisation [FAO], 2001; Wezel et al., 2009). Many integrated farms in the southern parts of Asia were found to be using integrations that had been structured and restructured by government and non-government organisations in agreement with the regional climate. These interventions have sufficient potential for rural prosperity. Agricultural improvements can solve issues such as unemployment and environmental degradation, while simultaneously enhancing food security, increasing the demand of livestock items, expanding crop diversity, and mobilising the traditional knowledge base to make integrated farming sustainable.

2.2. IFS and agro-ecological practices

Some authors comprehend IFS as a mixed farming system that consists of at least two separate but mutually-dependent parts of crop and livestock enterprises (Al Mamun, Nusrat, & Debi, 2011; Okigbo, 1995). Others describe IFS as an aquaculture system integrated with livestock, in which fresh animal waste is used to feed fish (Devendra & Thomas, 2002; Edwards, 1997). In the Indian sub-continent and many other tropical countries, IFS is a traditional mixed animal-crop system, where the livestock are raised on agricultural waste/by-products and animal is used to cultivate soil and provide crop nutrient and fuel (Jayanthi, Rangasamy, & Chinnusamy, 2000). In summary, IFS has been defined as a type of mixed farming system that allows crop and livestock enterprises to complement one another (Agbonlahor, Aromolaran, & Aiboni, 2003) to increase revenue and potentially minimise the risks of farmers (Radhamani, Balasubramanian, Ramamootthy, & Geetalakshmi, 2003). The overarching goal of IFS is to remain cyclically sustainable, where outputs of a specific enterprise can be used as the input for another system within the same and adjacent farm. Few authors have expanded the interaction to the use of off-farm resources and agro-industries (Prein, 2002). Farming system integration is part of a socio-ecological process that is dependent on the economic interests of the farm family. Farmers play essential roles in making decisions for their land, and their choices are defined not only by their socioeconomic status, but also by the spirit of their culture and ethics (Cheshire, Meurk, & Woods, 2013). IFS is not precisely the same as agro-ecological systems since the focus of IFS is more on integration among farm components for intensifying farming and may not follow other principles of agro-ecological farming such as use of little or no external input and high dependence on family labor. Nevertheless, IFS embodies the core principles of agroecology and provides opportunities for the application of methods taught in agro-ecological farming.

IFS is focused on the embodiment of agro-ecological principles, a discipline that evolved in response to the ecological and socioeconomic problems related to modern agriculture (Amekawa, 2011). In particular, fundamental ecological principles allow agricultural systems to be studied, designed, and managed to their fullest potential, with the intention of conserving natural resources. Agro-ecological restoration also allows farmers to re-integrate natural systems into their farming practices in order to maximise the sustainability and biodiversity of their farm (Campbell et al., 2012). The core principles of agroecology include organic matter accumulation and nutrient cycling, enhancing soil biological activity, promoting natural control mechanism, the general enhancement of biodiversity, and synergy among ecological components (Altieri et al., 2012). Agroecology also encompasses the socio-ecological aspects of farming and consequently manipulates systems for improved performance. Certain traditional practices utilised by farmers in developing nations, such as green manures, intercropping, agroforestry, and crop-livestock mixtures are common in IFS also, and they bring about improvements in various components of a farming system (Bisht et al., 2014). The connection between agroecology and interventions in farming systems can strengthen the implementation of IFS, since IFSs are ideally constructed following ecological processes, which is responsive to the changes in internal and external environment of small farms. The incorporation of "agro-ecological" integrated farming seeks to provide sustainable livelihoods at the farm and community level, benefiting the smallholders and the individuals they support.

2.3. Incorporating IFS into livelihood frameworks: A proposed model

Eighty percent of the farmland in sub-Saharan Africa and Asia is managed by smallholders (working on up to 10 hectares) (Conceição, Levine, Lipton, & Warren-Rodríguez, 2016). While 75% of the world's food is generated from only 12 plant and 5 animal species, making the global food system highly vulnerable, biodiversity is key to smallholder systems who keep many rustic and climate-resilient varieties and breeds alive (Hazell & Wood, 2008). Also, out of the 2.5 billion people in poor countries living directly from the food and agriculture sector, 1.5 billion people live in smallholder households (Altieri et al., 2012). Many of those 80% of the farmlands in sub-Saharan Africa and Asia is managed by smallholder households, which are extremely poor. Overall, the highest incidence of workers living

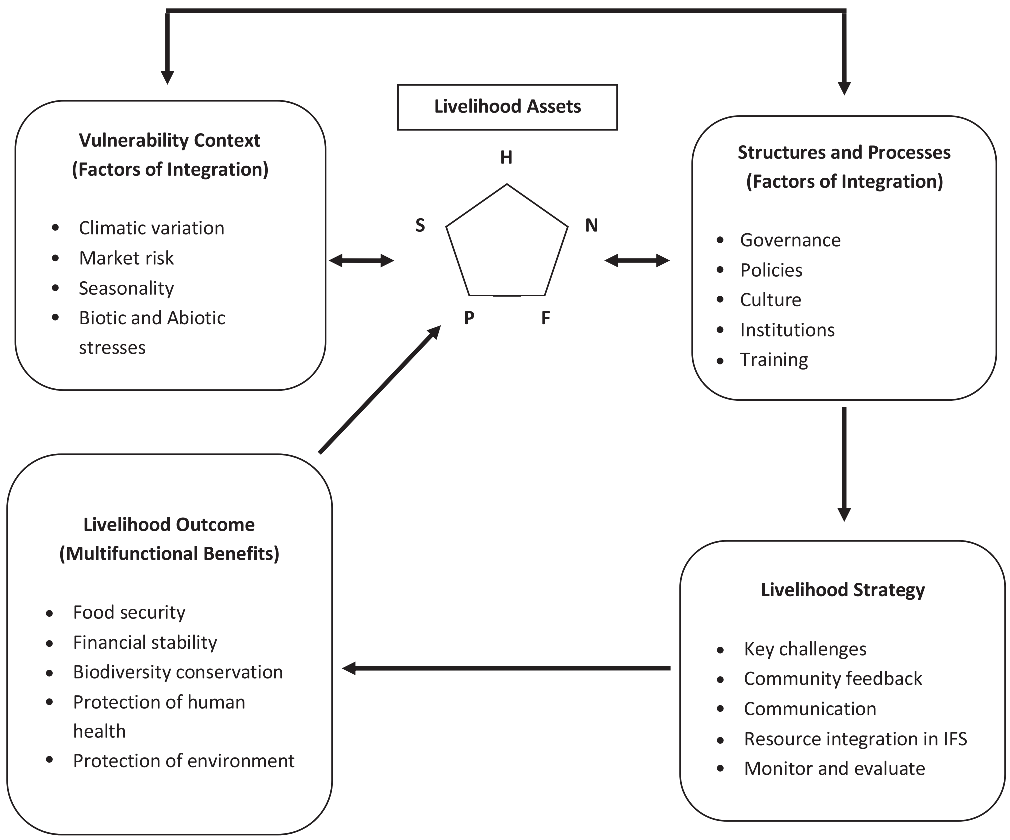


Figure 1. A schematic and modified model of standard integrated framing system.

Notes: Here, five capital resources are denoted as S: social, N: natural, H: human, P: physical, and F: financial.

with their families below the poverty line is associated with employment in agriculture (Davis et al., 2010). The economic viability and contributions to diversified landscape and culture are threatened by competitive pressure from globalisation and integration into common economic areas, so their fate is either to disappear and become purely self-subsistence producers, or to grow into larger units that can compete with large industrialised farms (e.g. current operational agricultural industries in developed countries) that is realistically a far-reaching option. This has motivated us to rethink the existing models of farming systems vis-à-vis sustainable livelihoods and modify them to suit the realities of smallholder integrated farmers of developing nations.

It has been observed that sustainable agriculture practices in developing countries prioritise food and community livelihood security. There is also a tendency for slow, standardised changes in farming towards agro-ecological practices (Gafsi, Legagneux, Nguyen, & Robin, 2006). This calls for a proposed model that utilises IFS in the context of creating sustainable livelihoods that can be implemented as both a strategy and outcome of agricultural development. This framework has been created in the hope of encompassing different hierarchies of a region's IFS, and to remain dynamic in the face of variations in a given community. Policy formation will follow appropriate research and extension strategies for agricultural development, as this feat cannot be accomplished without making entire farming systems function with greater efficiency. Since IFS contains both ecological and socioeconomic issues, the proposed framework must encompass a broad range of development criteria and incorporate interdisciplinary agricultural research and extension.

A smallholder family farm depends on the accessibility of five forms of capital: social, natural, human, physical, and financial. Figure 1 describes the SL framework that can assess environmental as well as socioeconomic conditions in terms of these five types of capital, applied mostly at the individual or household level to promote community-based improvements. Initiated primarily by multilateral donor agencies and international NGOs, sustainable livelihood frameworks are composed of five forms of assets, which are utilised within the context of vulnerability, and structures necessary to pursue a combination of livelihood strategies leading to desired livelihood outcomes. A smallholder integrated farm depends on the access and use of the asset pentagon—natural (soil quality, water quality, biodiversity); physical (electricity, machinery); human (knowledge, skills); financial (savings, disposable assets); and social capital (networks, trust, support systems). It makes use of the assets within the context of vulnerability (trends, shocks, and seasonality); structures (government, private) and processes (policies, laws, and incentives), which define their livelihood options (Rao & Rogers, 2006). "Vulnerability" is manifested in terms of trends in market price, shocks such as biotic/abiotic stresses, and seasonality affecting farming; and "structures" connote institutional arrangements affecting farming and marketing of farm produce. Based on the asset holding, vulnerability and institutional and policy context (i.e. structures and processes), a farm household takes up one or more farm enterprises as livelihood strategies to achieve desirable production, food security, cash income, etc. i.e. livelihood outcomes.

The resource-poor smallholders of developing countries strive to sustain livelihoods, and IFS must help them to achieve long-term sustainability. Unfortunately, there is a dearth of literature on how farmers' resource integration initiates livelihood processes and outcomes, and how they are governed by geographic, socioeconomic, political, and cultural contexts. A general lack of attention to

Table 1. Global examples of integrated farming systems and factors

Country/region	Form of integration	Factors influencing integration	Author, year
European nations	Mutually-supportive and dependent agricultural enterprises Agriculture, aquaculture, livestock integration	Biotic and abiotic stress, policy decisions that promote bio-diverse farms, awareness of ecological benefits of integrated farms	Edwards (1997)
Japan	Mixed farming system consisting of at least two separate but logically interdependent components	Natural resource depletion, demand for multiple crops, techno-economic reasons	Okigbo (1995)
India	Mixed crop system involving livestock component Minimizing risk, increasing production and profits while improving the utilization of organic wastes and crop residues	Techno-economic reason, policy decision, biotic and abiotic stress (e.g. land encroachment, reverse tenancy, erratic rainfall, etc.), natural resource depletion etc.	Jayanthi et al. (2000)
USA	Multifunctional systems and multiple roles assigned to agriculture Returns from waste- and irrigation water management	Total factor productivity, system stability, climate adaptability, maintaining sustainability of the system	Groenfeldt (2006)
Bangladesh	Short duration fisheries with paddy and mixed farming systems	Self-sufficiency of SHF to minimize risk, increase climatic resilience and market resilience	Das Gupta, Singh Babel, Albert, and Mark (2005), Al Mamun et al. (2011)
African nations	Aquaculture, agricultural farms, mixed farming systems with emphasis on livestock	Diversified demand of food sources, enhanced nutrition, biotic and abiotic stress in the ecosystem	Neori et al. (2004), Mahanjana and Cronje (2000), Agbonlahor et al. (2003)
China and South East Asia	Emphasis on permaculture, fishery and livestock	Waste and irrigation water management, indigenous knowledge of farming, biotic and abiotic stress	Devendra and Thomas (2002)

Notes: This table only contains a few selected published works on different countries for past few decades as examples. Additional examples are in the text but there are many other similar examples not cited to conserve space. The search criteria were different integration strategies undertaken by smallholder farm (SHF), along with the factors influencing the integration.

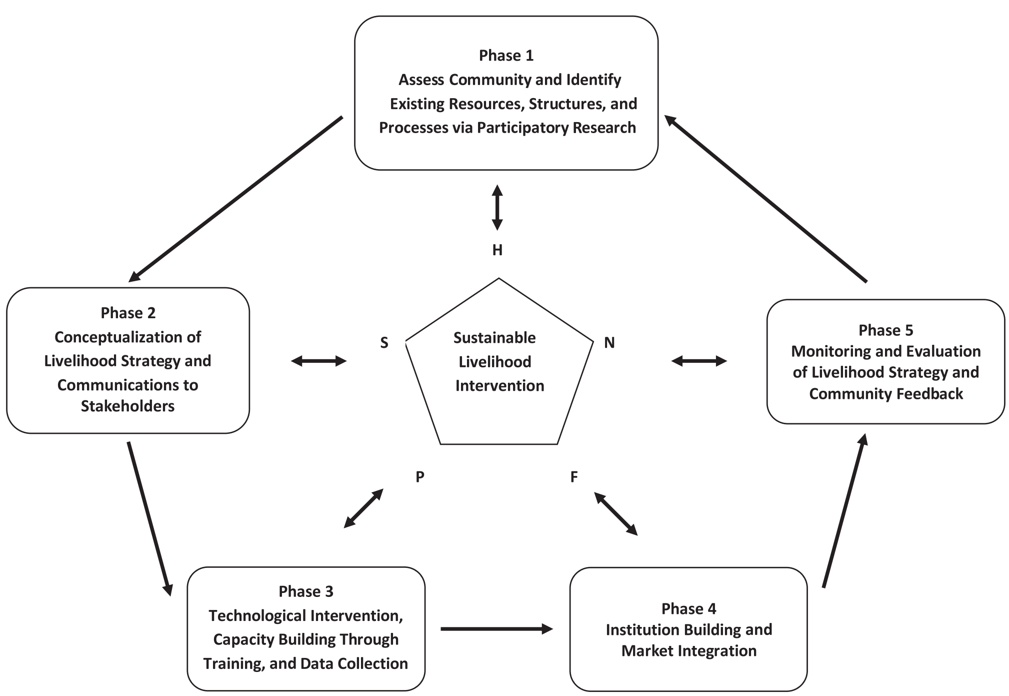
sustainable livelihoods in the literature on agroecology in general and IFS in particular needs theoretical attention. Resource integration in SHF must be viewed as a livelihood strategy, consciously undertaken by farm families. Integration among farm resources is generally not an outcome of mainstreamed research and extension (i.e. adoption of technologies and promoting integration), but depends on multiple factors in farming systems. Table 1 illustrates a few examples of the different integration strategies undertaken by SHF around the globe, along with the factors influencing these farming practices.

To address the dynamic nature of IFS, we suggest a process-based modeling approach to integrated farming, rather than a static model. The proposed SL process (Figure 2) suggests that both farmer-led innovations and their adoption of external technologies are conscious decisions that provide various benefits to the farm families. Policymakers should consider the circumstances that allow for integration in small farms and adjust formal agricultural research accordingly. For example, if there are variations in rainfall patterns, such as a delayed onset of monsoon season, farmers might excavate farm ponds and use the harvested rainwater to maintain the critical irrigation need of their crops. Hence, the research might focus on rain-water harvesting and broader issues of water-efficient farming. The concept of agricultural multifunctionality is considered as the livelihood outcome of farm families. This bridges the ecological processes in IFS with the diverse livelihood needs of resource-poor farmers. Several such functions are food security, financial stability and spread of marketing risks, conservation of plant genetic resources, sustenance of women's roles in smallholder agriculture, peasant resistance against agricultural liberalisation, coping with economic crisis, reproduction of local culture, and protection of human health and the environment (Amekawa, 2011). This conceptualisation is important for developing countries where outcome of farming is mostly subsistence in nature with a focus on risk avoidance; and farmers are often unaware of the associated benefits being produced by their farming activities such as reduced emissions and increased carbon storage.

We propose five major sets of process integration in the standard SL Framework (Figure 2). First, we consider agro-climatic situation, bio-physical properties, socio-politico-cultural atmosphere, and techno-economic conditions along with "vulnerabilities" (i.e. shocks, trends, and seasonality) and "structures and processes" (i.e. institutional arrangements and policy environment) as the context of IFS-driven livelihoods. This is important since the context of using livelihood assets must account

Figure 2. Proposed process for community-level integrated farming system intervention that incorporates established livelihood frameworks and project phases as a cyclic adaptation of the standard sustainable livelihood framework.

Notes: Here, five capital resources are denoted as S: social, N: natural, H: human, P: physical, and F: financial.



for ecological factors and socio-political processes. Second, we consider resource integration or adoption of technologies facilitating integration in small farms as a livelihood strategy consciously undertaken by farm families as a response to the change in micro- and macro-level factors of rural livelihood scenario. Third, the concept of agricultural multi-functionality (Huylenbroeck & Durand, 2003) is considered as the livelihood outcome of farm families. This bridges the ecological processes in IFS with diverse livelihood needs of resource-poor farmers and is mentioned in the previous paragraph.

However, this conceptualisation is never complete unless we scale it up for the whole community for which development interventions are often directed. We amalgamate the livelihood framework with a project-cycle management model to arrive at a cyclic adaptation of the SL framework for community-level intervention with IFS (Figure 1). A cycle typically starts with the analysis of a community's situation. Following the SL framework, this envisages the study of a community infrastructure (the five capitals, as described in Figure 1), vulnerability analysis, and assessment of institutions and policy. These components have been adopted from Berti, Julia, and Fitzgerald (2004) who described these factors as the most important areas of potential investment. Similarly, biotic and abiotic stresses, market uncertainties, and climatic variability form the vulnerability.

To address these various dynamic attributes of IFS, we proposed a new model that is mostly process-based (Figure 2). First, rural development administration and public policy may be studied through participatory research to understand the larger context of IFS intervention and inform community-level interventions. At the second phase of the cycle, the project team conceptualises the desirable livelihood outcome for the community such as higher production, income, resilience, food security, well-being, etc. Based on the phase 1 findings and desirable livelihood outcome, suitable IFS design is communicated and proposed to stakeholders (phase 2). For example, if perennial water bodies and readymade market for fish is available, design of IFS may be based on water bodies (e.g. fishery livestock or rice-fish-duck). Then, precise technological interventions such as composting, scientific aquaculture, backyard poultry, etc. may be practiced through training, based on the IFS designs, on which training and input support will be planned (phase 3). Parallel to phase 3, institution building and market integration is done. The institutions may be farmer clubs, farmer interest groups, self-help groups at the micro level, followed by their cluster and federation formation at higher scales. These are supported by farmer collectives such as cooperatives and farmer-producer companies (phase 4). In summary, the model is characterised by local resource-based IFS development, supported by sound science and technology interventions, and sustained by strong institutional arrangements leading to desirable livelihood outcomes for a community. In phase 5, the measurement and community feedback for the need of desirable livelihood lead to creation of infrastructure and reduced vulnerabilities of the community (Timmer, 2012). See Dasgupta, Goswami, Ali, Biswas, and Saha (2014) for a similar model proposed in the context of coastal West Bengal in eastern India.

2.4. Implications of conceptualising IFS within SL frameworks for agricultural research and development

The adoption and/or diffusion of innovations, especially in the sphere of natural resource management, have long been explained by the adoption of innovation theory (Rogers, 1995). This theorisation is severely challenged when explaining acceptance of sustainable agro-ecological practices such as IFS. Due to the unique characteristics of IFS (a combination of innovations/management practices) and its implementation in rural communities, ensuring the acceptance of agro-ecological practices can be challenging in smallholder systems. These challenges are effectively addressed when the innovations provide benefits to smallholders that lead to less-complex and more-compatible agricultural practices. An important factor to consider is that IFS remains a socio-ecological practice rather than a material technological intervention. The promotion and adoption of IFS would be limited if it was offered as a bundle of defined technologies, even if location-specific IFS were offered to the farmers. Conceptualisation of the integrations in IFS as a livelihood strategy resolves this potential limitation, and encourages the introduction of technologies that initiate integration between/among farm resources by clearly defining the desirable livelihood outcomes. For example, integration may be planned at the plot level for crops or at the enterprise level for farmers, depending on the desired livelihood outcome. Proposed intervention will certainly differ when the goal is purely risk-aversion and not integrated with the market. The intervention may involve composting, crop rotation, resource integration, bio-digester, or landscape planning, leading to higher yield, improved soil fertility, and increased risk aversion. Any of this intervention must be administrated through organised training, followed by frequent visits (Banerjee et al., 2015) and communications. This may be supported by appropriate endogenous institutional arrangement—such as seed-sharing network, farmer field school—for social sustainability. Promoting indigenously-developed IFS with small adaptations is preferred since this embodies tested response of smallholders to many external factors including knowledge, attitude, and perceptions (Meijer, Catacutan, Ajayi, Sileshi, & Nieuwenhuis, 2015). Ideally, the models should be built over a period of time instead of imposing a standard model, and the intervening agency should withdraw when little or no external inputs are needed in an IFS. The intervention is also expected to achieve higher sustainability with market opportunities when planned as a cluster of IFS, instead of individual IFS. These clusters may be administered by appropriate institutional arrangement at the grassroots. However, both individual IFS and cluster of IFS may be opted in different contexts at different time frames.

The proposed modifications in SL framework have several implications for agricultural research and extension. Extension in developing nations either transfers individual technologies, including nutrient management and plant protection, and farm implements, or promotes IFS as a defined bundle of technologies with little flexibility. The focus is, almost invariably, on productivity and profitability in SHF. In contrast, voluntary organisations tend to idealise the agro-ecological process as alternative agriculture and emphasise subsistence and ecological processes. This results from a lack of a standardised framework that accommodates ecological processes that influence socioeconomic outcomes including market functions. Agricultural research and extension should build on the context that leads to integration in small farm and adjusts formal agricultural research accordingly. For example, in case of farm-pond excavation for critical irrigation to staple crops, extension facility should concentrate on excavation of farm ponds and capacity building of farmers for its scientific use so that integration can take place using the farm pond. This will ask for introduction and research on drought-resistant varieties, late-sowing varieties, and aerial cultivation of vegetables on the pond, instead of introducing IFS as a “technological bundle”. This will need strong linkage between research and extension sub-system and participation of farmers in developing IFS models through on-farm assessment and refinement of standard models. On the other hand, the concept of multifunctional agriculture involves food security, diversification of crops, ecological conservation, adjusting to the volatility of open market, and preserving local culture. In our proposed model, IFS illustrates these desirable livelihood outcomes for SHF. These outcomes may reflect both farmers’ and policy’s priorities, and can be important considerations for research and extension. Moreover, measure of success of extension programs should also be assessed in terms of generating multiple benefits from farming and not in terms of technology adoption or production enhancement only. We have summarised the novelties of our proposed model over the existing model of IFS design and promotion, and have given their possible implications for smallholder systems of the developing countries (see Table 2).

Table 2. A comparison between existing models and proposed models for integrated smallholder farming systems

	Existing model of IFS design and promotion	Proposed model	Implications for smallholders
Conceptualisation of the technology	A bundle of technologies defining an IFS, for a wide geographical area	Single technology that facilitates integration in farming system	Helps in the development of appropriate technology in diverse smallholder system
Conceptualisation of integration	Integration as physical/biological process of resource recycling and or utilization	Strategic integration (beside physical/biological process) to achieve desirable livelihood outcome	Helps in achieving perceived priority in smallholder farms, often leading to coping up of risk
Conceptualisation of the context for technology development	Little consideration is given to both internal and external factors affecting farming at the farm level	Consideration for agro-climatic, bio-physical, socio-politico-cultural, and techno-economic conditions along with "vulnerabilities" and "structures and processes"	Higher chance that the technological intervention is more problem solving in nature
Technology development	Developed in controlled environments of research stations, parameter of success being measured in terms of agronomic (yield) and economic (profit) concerns mostly	Developed through participatory on-farm research with farmers as partners, parameter of success being measured in terms of social (food security), economic (profitability), and ecological (biodiversity)	Development of appropriate technology and more likely to be adopted in smallholder system
Technology refinement	Limited provision within the research and extension system, takes place at the farm level, if the model is at all adopted	Participatory on-farm research emphasises farm-level refinement of the technology	Higher chance of technology adoption and utilization
Technology transfer	The IFS model itself is transferred, incurs high initial cost—either for the extension or by the farm family	Transfer of technology that facilitates integration in IFS is relatively simpler, less costly	More efficient transaction cost in part of the research and extension system
Conceptualisation of outcome of technology	Higher yield and income	Multifunctional—social, economic, and ecological	Development of understanding on smallholder priority and ecosystem services integrated in the model
Scaling up of technology	Conventional assumptions of diffusion of innovations, dependence on conventional extension methods	Technology development and use within the community context with due consideration of market as a sustaining component	Enhance community-level prosperity through technological intervention, integration of smallholder system with market
Formal agricultural research and development	Limited scope of accommodating biologists and social scientists working together	Scope of biologists and social scientists working together	More interdisciplinary understanding, beneficial for the development of appropriate technology for smallholders

3. Conclusions

IFS has the capacity to help smallholders in developing countries to achieve long-term sustainability. Recent literature explains that farmers' resource integration initiates livelihood processes and outcomes, but does not make it explicit how the process might be improved in terms of the manner they are governed by surrounding geographic, socioeconomic, political, and necessary cultural adjustments, except a few exceptions (e.g. Banerjee et al., 2015). There has been a general lack of attention placed on sustainable livelihoods in agroecology research and IFS in particular. With this in mind, we conceptualise resource integration as a conscious livelihood strategy of smallholder resource-limited farmers that results in multifunctional benefit in small farms. In doing so, we tried to bridge the gap between production ecology and socioeconomic outcome of agro-ecological practices. The conventional policies regarding agriculture and rural development have largely been externally driven, and have posed an overwhelming emphasis on productivity and profitability. This is not suitable for the livelihood realities of smallholder farmers in developing countries. Marginal farmers operating in fragile ecosystems in these nations hardly benefit from such policy frameworks, often suggested by multilateral donor agencies. In any instance, smallholders' primary focus is on subsistence with reduced risk, followed up with cautious diversification in farming systems (Shiferaw, Okello, & Reddy, 2009). Studies have shown that agro-ecological farming, specifically IFS, has contributed to secure livelihoods of rural smallholders (Tipraqsa et al., 2007). We have tried to contextualise IFS within the SL framework to establish it as a means to improve community livelihoods, instead of viewing them as an outcome of technological intervention. From our working experience, we hypothesise the multiple benefits of conscious resource integration in farming systems as livelihood outcomes in SHF, and introduce IFS as a process of strategically promoting "integrative" technologies.

Agricultural developments among farmers imply that interdisciplinary collaboration should be increasingly utilised in academic research. This requires two transformations in the scholarship on smallholder agriculture. First, ecologists, agronomists, entomologists, soil scientists, veterinary scientists, and plant scientists must work alongside social scientists in order to conduct applied research. Second, a formal working environment must be created in the agricultural (both animal and plant) research and extension system where applied biologists can work with socio-economists. For example, in most developing nations, there is little scope of such collaboration in the government-led agricultural research systems where little or no formal engagement of socio-economists (e.g. sociologists, economists, anthropologists, etc.) is found, and practically no interdisciplinary courses on applied biology and ecology (such as agroecology) are offered in agricultural universities. These two issues, if properly addressed, can meet the needs of trained human capital and produce a combined knowledge that can specifically focus on integrated forms of smallholder agriculture. Agroecological practices such as IFS accurately incorporate social and ecological complexities more effectively than conventional agriculture, and informed implementation of IFS demands an appropriate institutional environment that supports multiple desirable livelihood outcomes from farming. This implies facilitation of a multiple stakeholder environment involving farmers, researchers, extension workers, local leaders, agricultural systems, colleges, and universities as partners of IFS planning, so far not well-linked with the extension systems in most of the developing nations. Our proposed model of IFS implementation involves dynamic resource integration, within the larger context of rural development, and overall enhanced outcomes of sustainable livelihoods at the community level through an integrated process-based approach.

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